Physics 571 – Modern Atomic Physics

Spring, 2014, Randy Hulet

Research activity in *Atomic, Molecular and Optical science* (AMO) has grown rapidly over the past 15-20 years, particularly in the field of *ultracold atomic physics*. This growth is due to the development of novel techniques for laser cooling and evaporation which has moved the low temperature frontier into the nano-Kelvin regime. Access to ultracold temperatures has enabled applications such as ultra-precision spectroscopy, new types of atomic clocks, and atomic gyroscopes. At sufficiently low temperatures, a gas of atoms becomes quantum degenerate where bosonic atoms undergo a transition to a *Bose-Einstein condensate* (BEC), and where fermionic atoms may pair to become a superfluid. This research has provided new insight into the quantum world and provides a new domain for exploring many-body physics.

The aim of Physics 571 is to provide the student the foundation of quantum mechanics and atomic physics needed to master this exciting new field. We will start with some traditional atomic physics of hydrogen and hydrogen-like atoms, followed by the study of atom-photon interactions. With this background, we will discuss various cooling and trapping techniques for neutral atoms, and finally, the remaining lectures will focus on the study of quantum degenerate gases.

I. Atomic Physics

A. Hydrogen and hydrogen-like atoms

1. Non-relativistic theory (review); atomic units
2. Fine and hyperfine structure
3. Effect of static magnetic fields
4. Lamb shift and spontaneous decay

B. Atom/photon interactions

1. Density matrix and optical Bloch equations
2. Dressed states
3. 3-level systems: Autler-Townes effect, dark states
4. Laser spectroscopy

C. Cooling and trapping of neutral atoms

1. Light pressure forces
2. Atom cooling: Doppler, evaporative
3. Atom trapping: magneto-optical, magnetic, optical
4. Optical lattices

II. Quantum Degenerate Gases

A. Bose-Einstein condensation

1. BEC in an ideal gas
2. Atomic collisions and the scattering length; Feshbach resonances
3. Weakly-interacting atomic condensate

B. Quantum degenerate fermions

1. Equilibrium properties
2. BEC-BCS crossover

Reference Books:

"Atomic Physics", by C. J. Foot

"Advances in Atomic Physics: An Overview", by C. Cohen-Tannoudji and D. Guéry-Odelin.

Also useful, but not required: "Bose-Einstein Condensation in Dilute Gases", by C. J. Pethick and H. Smith.

Grading:

40% of the grade is based on homework, 30% on a class presentation on a current research topic, and 30% on an oral final exam.

Working together on problem sets is encouraged, but consulting prior year's homework or solutions is a violation of the honor code.

Any student with a documented disability needing academic adjustments or accommodations is requested to speak with me during the first two weeks of class. All discussions will remain confidential. Students with disabilities will also need to contact Disability Support Services in the Ley Student Center.